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A COMPARISON OF WEIGHTING TECHNIQUES FOR SAW TRANSDUCERS AT UHF

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Air Force Systems Command
Griffiss Air Force Base, New York 13441

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A comparison is made of several constant-finger-overlap, interdigital transducer-weighting schemes for realizing low sidelobe, SAW, bandpass filters between 330 and 340 MHz. Withdrawal weighting yields slightly superior performance, but source weighting allows simpler design procedures. The neglect of near-neighbor interactions (all 1's design) yields relatively poor results. Source-weighting tables are provided in an Appendix.

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Preface

Some of the topics discussed in this report evolved from a discussion with Dr. W. R. Smith of Hughes Aircraft Co. at the 1977 Ultrasonics Symposium.

Contents

Illustrations

Tables

A Comparison of Weighting Techniques for SAW Transducers at UHF

I. INTRODUCTION

Withdrawal-weighted transducers[1,2] have proven to be extremely valuable in the realization of narrow bandwidth, low sidelobe, surface acoustic wave (SAW) filters.[3] In this paper, withdrawal-weighting (WW) techniques are compared to other constant-finger-overlap schemes, which also depend on near-neighbor effects to obtain variable electrode weights. ST quartz and a double electrode finger overlap of 500 μm are used throughout. Motivation was provided by the hope to eliminate the velocity correction[4] required in standard WW design, and by the potential for improved performance.

The three major types of weighting to be described are shown schematically in Figure 1 and are defined in detail in Table 1. In withdrawal weighting, as defined

(Received for publication 13 February 1981)

1. Hartmann, C.S. (1973) Weighting interdigital surface wave transducers by withdrawal of electrodes, Ultrasonics Symposium Proceedings, IEEE, pp 423-426.
2. Laker, K.R., Cohen, E., Szabo, T.L., and Pustaver, J.A., Jr. (1978) Computer-aided design of withdrawal-weighted SAW bandpass filters, IEEE Trans. on Circuits and Systems, CAS-25:241-251.
3. Slobodnik, A.J., Jr., Roberts, G.A., Silva, J.H., Kearns, W.J., Sethares, J.C., and Szabo, T.L. (1979) Switchable SAW filter banks at UHF, IEEE Trans. on Sonics and Ultrasonics, SU-26:120-126.
4. Wagers, R.S. (1974) Phase error compensation in finger withdrawal transducers, Ultrasonics Symposium Proceedings, IEEE, pp 418-421.

here, electrodes from a strictly alternating sequence are simply removed. For source weighting, all electrodes are present, but assignment to a particular pad is determined by the design algorithm. Combination weighting is essentially a combination of the other two types.

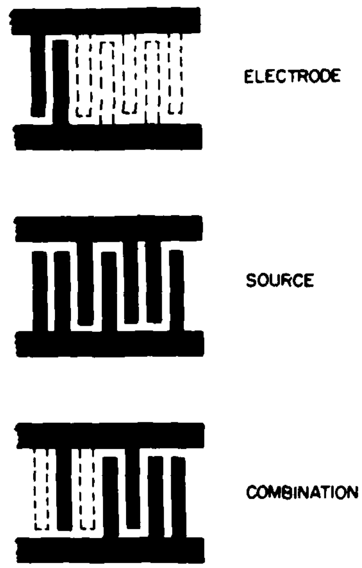


Figure 1. Three Types of Constant-Finger-Overlap Weighting Schemes

Table 1. Definitions of the Constant-Finger-Overlap, Interdigital Transducer-Weighting Schemes Considered in This Paper

Withdrawal weighting simply removes electrodes from a strictly alternating transducer.
Restricted source weighting first removes an odd number of electrodes, then fills in with dummies.
General source weighting allows arbitrary assignment of electrodes to pads in a filled-in array.
Combination weighting allows arbitrary pad assignment and/or full removal of electrodes.

Source weighting[5] is of interest since a filled-in transducer does not require the velocity correction that is necessary when both free surface and electroded

5. Smith, W. R., and Pedler, W. F. (1975) Fundamental- and harmonic-frequency circuit-model analysis of interdigital transducers with arbitrary metallization ratios and polarity sequences, IEEE Trans. on Microwave Theory and Tech. MTT-23:853-864.

sections are present. (Source-weighting tables are provided in Appendix A.) Combination weighting offers the advantage of many more available weights, as illustrated in Figure 2. In addition, since general source weighting and combination weighting both allow arbitrary assignment of electrodes to pads, impulse response functions having time-domain nulls can be synthesized.

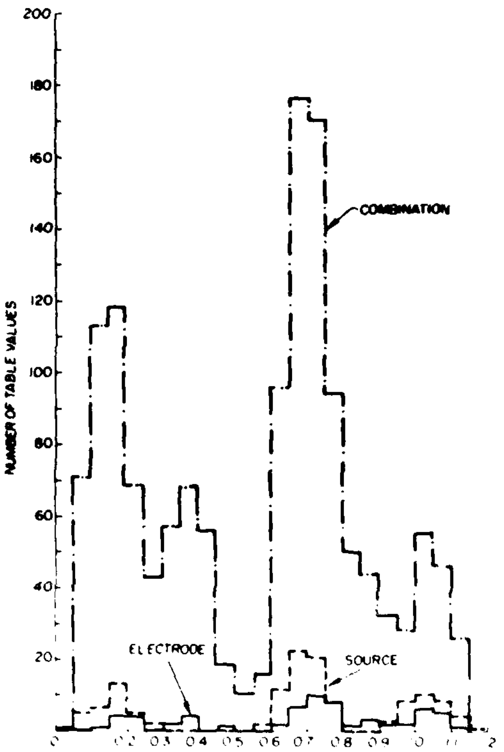


Figure 2. Distribution and Number of Individual Electrode Weights for Three Types of Constant-Finger-Overlap Weighting Schemes. Data shown is for double electrodes. Horizontal axis indicates table values ranging between 0 and 1.2

2. AN ALL ONE'S DESIGN

Before discussing the three types of weighting, let us first examine an all 1's design and compare it to a regular withdrawal-weighted filter. An all 1's transducer is particularly easy to implement, since all near-neighbor effects[2, 6] are neglected in the design procedure. That is, electrodes present are assigned unity

6. Laker, K. R., Cohen, E., and Slobodnik, A. J., Jr. (1976) Electric field interactions within finite arrays and the design of withdrawal weighted SAW filters at fundamental and higher harmonics, Ultrasonics Symposium Proceedings, IEEE, pp 317-321.

weight and electrodes removed are given zero weight. *Unfortunately, this gross* assumption yields a rather poor device, as illustrated in Figure 3. Theory and experiment agree quite well and both yield the same conclusion: For an equal transducer length, the standard WW design (left) has lower sidelobes and a narrower passband than the all 1's device (right). Both designs attempted the synthesis of the same Hamming weighted bandpass filter, having an impulse response with a time duration of 0.92 μsec. Broadband transducers were used at the output in order to show only the response of the weighted transducer. In fact, these procedures are followed throughout this paper.

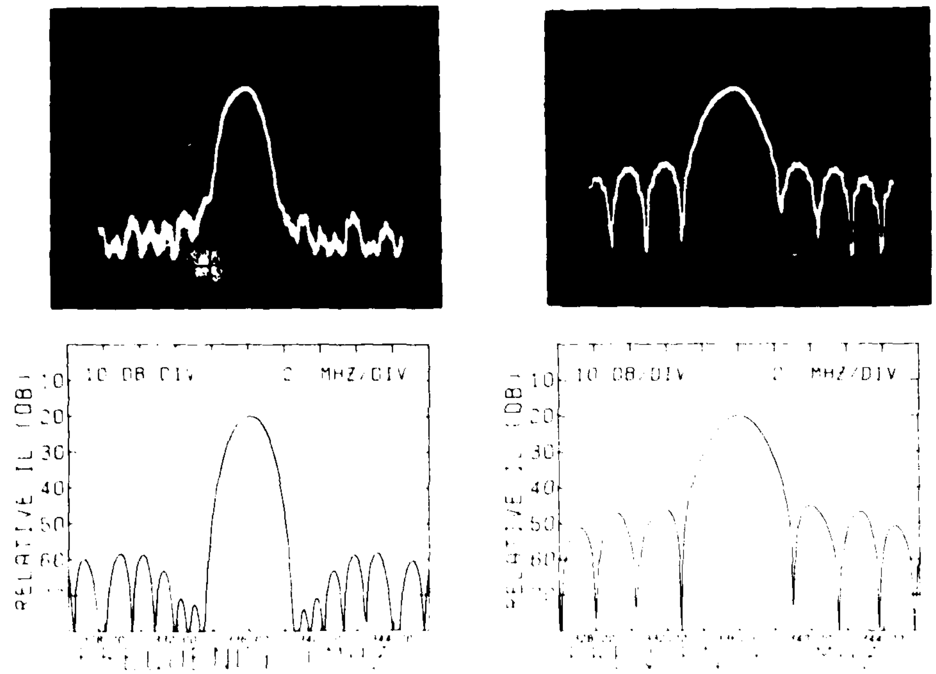


Figure 3. Relative Insertion Loss Versus Frequency Responses Comparing a Standard Withdrawal-Weighted Design (left) to an All 1's Design (right). Both are velocity corrected. Top: Experiment. Bottom: Theory

3. COMPARISON OF SOURCE AND WITHDRAWAL WEIGHTING

Let us now compare source and regular withdrawal weighting. Results of a detailed theoretical[7] comparison are shown in Figure 4. The original source

7. Tancrell, R.H., and Sandy, F. (1973) Analysis of Interdigital Transducers For Acoustic Surface Wave Devices, TR-73-0030, National Technical Information Services, Springfield, Virginia, 22151.

design (unmodified) shown in Figure 4A has a somewhat wider passband than the WW device of Figure 4B. Experimental confirmation is illustrated in Figures 5A and 5B.

The cause of this widening was traced to unwanted phase weighting at the electrodes caused by near-neighbor effects. In theory these phase deviations can be ideally corrected by shifting the positions of the electrodes, with results as shown in Figure 4D. Unfortunately, this design would be extremely difficult to realize in practice, because in order to prevent adjacent electrodes from touching or from having very small gaps, the electrodes must be significantly smaller than 0.125 wavelength (1.17 μm). In this case, 0.6 μm lines over an ~3 mm area would be required.

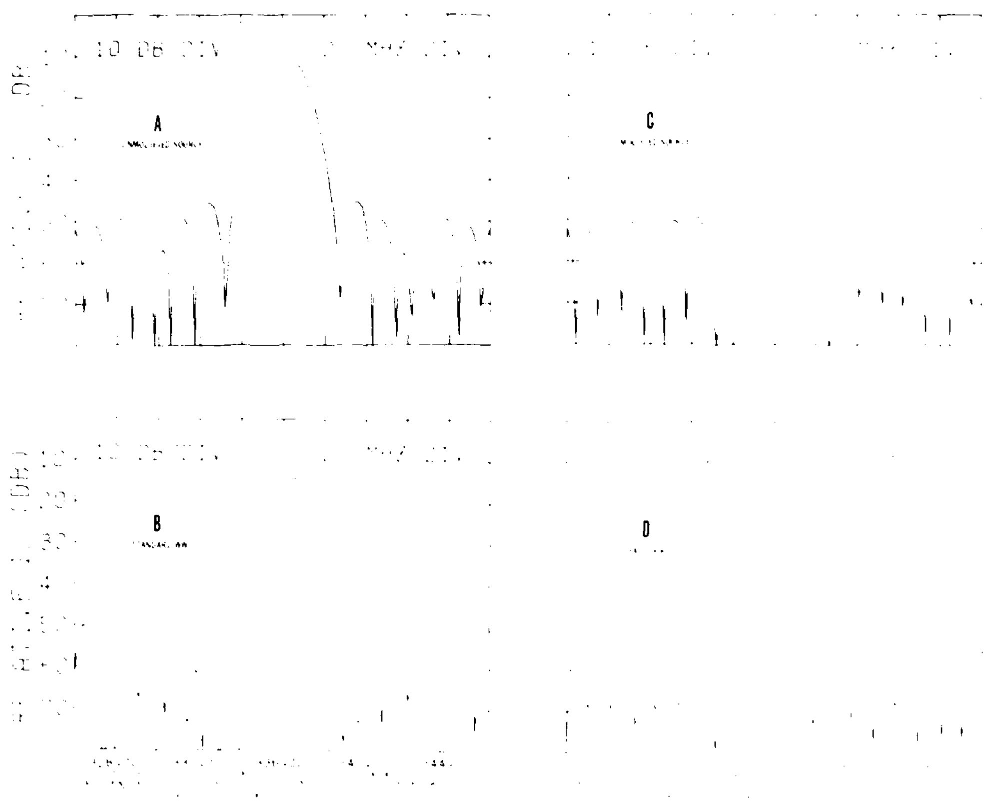
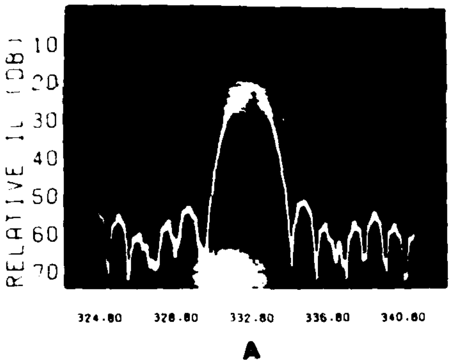
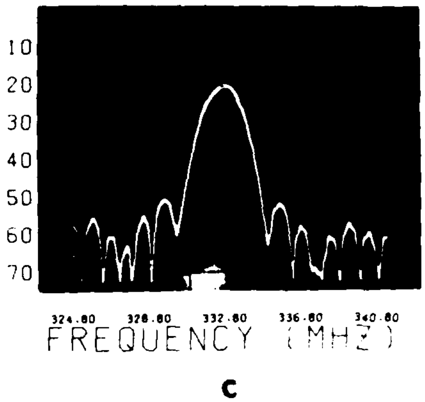


Figure 4. Theoretical Comparison of Source Weighted and Standard Withdrawal-Weighted Transducer Frequency Characteristics. The velocity difference between free and metalized surfaces is included in the analysis in all cases. (DELTERV = 0.0048, see Ref 8.) Velocity correction is needed and used only in the WW case

8. Slobodnik, A.J., Jr., Szabo, T.L., and Laker, K.R. (1979) Miniature surface-acoustic-wave filters, Proc. IEEE, 67:129-146.





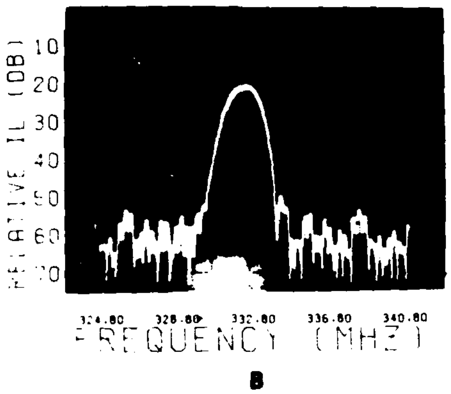


Figure 5. Experimental Relative Insertion Loss Results for Comparison to Figure 4:
A. Unmodified Source
B. Standard WW
C. Modified Source

The compromise (modified) design shown in Figure 4C utilizes only 40 percent of the total required phase compensation and reduces linewidths by only 6 percent over a strictly 1:1 linewidth-to-gap spacing ratio. Some improvement over the unmodified source characteristics of Figure 4A can be noted. Unfortunately, this improvement could not be observed experimentally, as seen in Figure 5C. The most likely cause is thought to be the round-off and stepping-inaccuracy limitations of the interdigital transducer mask generation machine.

Why should it be necessary to phase-correct a source-weighted transducer but not a regular WW structure? (Velocity correction of a standard WW is separate and is, of course, required.) One possible answer is that when an electrode is absent (withdrawn) it has identically zero phase. This, coupled with the presence of a large center portion of strictly alternating electrodes in a standard WW, means that there are few phase centers that potentially need correction.

A preliminary comparison of this modified source design and a combination weighted filter with velocity correction only is shown in Figure 6. No particular advantage in using combination weighting is evident. Applying phase correction to

the combination design did not result in any substantial improvement; also, the use of two correction steps (velocity plus phase) is an undesirably complex design procedure.

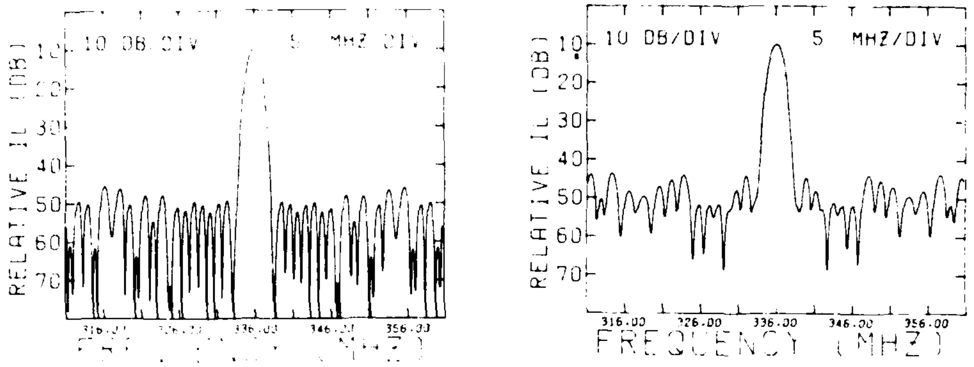


Figure 6. Theoretical Comparison of the Frequency Characteristics of a 40% Phase-Corrected, Source-Weighted Design (Left) With Those of a Combination-Weighted Device (Right)

4. SUMMARY AND CONCLUSIONS

Based on the results of this report, we conclude that withdrawal weighting with velocity correction yields somewhat superior filter performance compared to source weighting, which does not require velocity correction. That is, for a given transducer length, the WW design will yield a narrower passband. Thus a tradeoff is available: Use source weighting and eliminate one design step (velocity correction), or use withdrawal weighting for better performance. It should also be noted that recent work[9, 10] promises to eliminate the need for experimentally determining the velocity-correction parameter. Complete implementation of this new theory would lend additional bias to WW when compared to source weighting.

Since the bandwidth widening in source weighting was attributed to unwanted phase deviation, attempts were made to correct for this effect. Using practical phase correction in a source-weighted transducer could not experimentally improve

9. Datta, S., and Hunsinger, B. J. (1979) First-order reflection coefficients of surface acoustic waves from thin-strip overlays, J. Appl. Phys. 50:5661-5665.
10. Datta, S., and Hunsinger, B. J. (1979) A theoretical analysis of stored energy in surface wave gratings, Ultrasonics Symposium Proceedings, IEEE, pp 673-677.

the performance of these devices in the sense of narrowing the bandwidth for a fixed transducer length.

Combination-weighted devices showed no particular advantages. An all 1's design was simply not competitive from a performance standpoint.

It is concluded that, unless it is necessary to synthesize filters having time-domain nulls, withdrawal weighting is the preferred choice for high performance bandpass filters. Source weighting yields somewhat reduced performance with the advantage of one less design step. Where time-domain nulls are required, generalized source or combination weighting is necessary.

References

1. Hartmann, C.S. (1973) Weighting interdigital surface wave transducers by withdrawal of electrodes, Ultrasonics Symposium Proceedings, IEEE, pp 423-426.

2. Laker, K.R., Cohen, E., Szabo, T.L., and Pustaver, J.A., Jr. (1978) Computer-aided design of withdrawal-weighted SAW bandpass filters, IEEE Trans. on Circuits and Systems. CAS-25:241-251.

3. Slobodnik, A.J., Jr., Roberts, G.A., Silva, J.H., Kearns, W.J., Sethares, J.C., and Szabo, T.L. (1979) Switchable SAW filter banks at UHF, IEEE Trans. on Sonics and Ultrasonics, SU-26:120-126.

4. Wagers, R.S. (1974) Phase error compensation in finger withdrawal transducers, Ultrasonics Symposium Proceedings, IEEE, pp 418-421.

5. Smith, W.R., and Pedler, W.F. (1975) Fundamental- and harmonic-frequency circuit-model analysis of interdigital transducers with arbitrary metallization ratios and polarity sequences, IEEE Trans. on Microwave Theory and Tech. MTT-23:853-864.

6. Laker, K.R., Cohen, E., and Slobodnik, A.J., Jr. (1976) Electric field interactions within finite arrays and the design of withdrawal weighted SAW filters at fundamental and higher harmonics, Ultrasonics Symposium Proceedings, IEEE, pp 317-321.

7. Tancrell, R.H., and Sandy, F. (1973) Analysis of Interdigital Transducers For Acoustic Surface Wave Devices, TR-73-0030, National Technical Information Services, Springfield, Virginia, 22151.

8. Slobodnik, A.J., Jr., Szabo, T.L., and Laker, K.R. (1979) Miniature surface-acoustic-wave filters, Proc. IEEE, 67:129-146.

9. Datta, S., and Hunsinger, B.J. (1979) First-order reflection coefficients of surface acoustic waves from thin-strip overlays, J. Appl. Phys. 50:5661-5665.

10. Datta, S., and Hunsinger, B.J. (1979) A theoretical analysis of stored energy in surface wave gratings, Ultrasonics Symposium Proceedings, IEEE, pp 673-677.

Appendix A

Source-Weighting Tables

This Appendix provides source-weighting tables for single and double electrodes in environments consisting of three arbitrary nearest neighbors on each side of the electrode under study. Beyond these neighbors, an infinite, strictly alternating environment is assumed to exist in both directions. Note that a double electrode consists of two fingers and is assumed to be an inseparable unit.

The amplitude weights, $\hat{h}_o[N]$, and phase weights, $\hat{d}_o[N]$, are referenced to the weights of an electrode in a completely regular, infinite, strictly alternating environment. Plus signs refer to electrodes connected to the Positive pad or bus-bar of the transducer, while Minus signs refer to electrodes attached to the Negative pad. The sign of the electrode under study (or center electrode) is given in the upper-left-hand corner of the tables and the neighboring environments to the right and below. The polarity of the bus-bars is determined as follows: The pad to which the electrode under study (center electrode with three nearest neighbors on each side) would have been connected to in a completely regular, strictly alternating environment is defined as the Positive bus-bar. Positive tables should be used if the center electrode is actually connected to the Positive bus-bar and Negative tables if the opposite is true. Note that the completely regular, strictly alternating environment referenced above is created by simply extending through the center of the infinite environment that is always assumed to exist beyond the three nearest neighbors.

Positive Double Electrode Source Weighting Design Table (f_o)

$\hat{H}o(N)/\hat{d}o(N)$								
+	-+-	-++	---	--+	++-	+++	+--	+-+
-+-	1.000000 0.0	.966394 .001861	1.071924 -0.006016	1.038211 -0.004550	.661951 .098804	.636663 .099959	.714351 .094558	.687321 .096775
++-	0.966394 -0.001861	.932750 0.0	1.038433 -0.007955	1.004687 -0.006512	.630567 .099952	.605791 .100831	.682011 .096130	.655329 .098249
---	1.071924 .006016	1.038433 .007955	1.143461 0.0	1.109849 .001577	.733963 .096709	.708001 .098118	.787579 .092220	.760129 .094420
+--	1.038211 .004550	1.004687 .006512	1.109849 -0.001577	1.076211 0.0	.702203 .097891	.676654 .099121	.755030 .093670	.727867 .095818
-++	.661951 -.098804	.630567 -.099952	.733963 - .096709	.702203 - .097891	.125899 0.0	.092440 .015003	.198678 -.025601	.164675 -.022577
+++	.636663 -.099959	.605791 -.100831	.708001 - .098118	.676654 - .099121	.092440 - .015003	.058657 0.0	.166043 [illegible]	.131965 -.037781
--+	.714351 -.094558	.682011 -.096130	.787579 - .092220	.755030 - .093670	.198678 .025601	[illegible] [illegible]	[illegible] [illegible]	.235799 .006031
+-+	.687321 -.095775	.655329 -.098249	.760129 - .094420	.727867 - .095818	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	.202110 0.0

Negative Double Electrode Source Weighting Design Table (f_o)

$\hat{H}o(N)/\grave{d}o(N)$								
-	+-+	+--	+++	++-	--+	---	-++	-+-
+-+	.987614 0.0	.954006 .001893	1.059540 - .006103	1.025827 - .004618	.651448 .099307	.626403 .100320	.703370 .095313	.676517 .097456
--+	.954006 - .001893	.920366 0.0	1.026048 - .008076	.992305 - .006615	.620208 .100394	.595700 .101104	.671122 .096877	.644636 .098903
+++	1.059540 .006103	1.026048 .008076	1.131235 0.0	1.097464 .001599	.723279 .097249	.697516 .098559	.776489 .092939	.749188 .095089
-++	1.025827 .004618	.992305 .006615	1.097474 - .991599	1.063826 0.0	.691631 .098396	.666301 .099507	.744016 .094390	.717017 .096475
+--	.651448 - .099307	.620208 - .100394	.723279 - .097249	.691631 - .098396	.113513 0.0	.080081 .017329	.186362 -.027281	.152344 -.024409
---	.626403 - .100320	.595700 - .101104	.697516 - .098559	.666301 - .099507	.080081 - .017329	.046264 0.0	.153822 -.040970	.119743 -.041417
++-	.703370 - .095313	.671122 - .096877	.776489 - .092939	.744016 - .094390	.186362 .027281	.153822 .040970	.256973 0.0	.223418 .006377
-+-	.676517 - .097456	.644636 - .098903	.749188 - .095089	.717017 - .096475	.152344 .024409	.119743 .041417	.223418 -.006377	.189725 0.0

Positive Single Electrode Source Weighting Design Table (f_o)

Ho(N)/do(N)								
+	-+-	-++	---	--+	++-	+++	+--	+-+
-+-	1.000000 0.0	0.960016 0.000699	1.089448 -0.002160	1.049423 -0.001606	0.583704 0.040772	0.545635 0.044644	0.668853 0.032390	0.630186 0.035354
++-	0.960016 -0.000699	0.920018 0.0	1.049507 -0.002882	1.009471 -0.002336	0.543952 0.042526	0.506029 0.046794	0.628870 0.033414	0.590272 0.036636
---	1.089448 0.002160	1.049507 0.002882	1.178753 0.0	1.138767 0.000587	0.673657 0.038733	0.635422 0.041966	0.759035 0.031548	0.720309 0.034101
+--	1.049423 0.001606	1.009471 0.002336	1.138767 -0.000587	1.098771 0.0	0.633839 0.040120	0.595711 0.043634	0.719035 0.032398	0.680364 0.035142
-++	0.583704 -0.040772	0.543952 -0.042526	0.673657 -0.038733	0.633839 -0.040120	0.138283 0.0	0.098356 0.006633	0.228000 -0.010076	0.187880 -0.008755
+++	0.545635 -0.044644	0.506029 -0.046794	0.635422 -0.041966	0.595711 -0.043634	0.098356 -0.006633	0.058301 0.0	0.188348 -0.015637	0.148201 -0.015479
--+	0.668853 -0.032390	0.628870 -0.033414	0.759035 -0.031548	0.719035 -0.032398	0.228000 0.010076	0.188348 0.015637	0.317036 0.0	0.277068 0.002364
+-+	0.630186 -0.035354	0.590272 -0.036636	0.720309 -0.034101	0.680364 -0.035142	0.187880 0.008755	0.148201 0.015479	0.277068 -0.002364	0.237054 0.0

Negative Single Electrode Source Weighting Design Table (f_o)

Ho(N)/do(N)								
-	+-+	+--	+++	++-	--+	---	-++	-+-
+-+	1.052345 0.0	1.012360 0.000662	1.141789 -0.002059	1.101766 -0.001528	0.634849 0.037562	0.596535 0.040951	0.720447 0.030088	0.681636 0.032717
--+	1.012360 -0.000662	0.972363 0.0	1.101846 -0.002742	1.061812 -0.002217	0.594996 0.038969	0.556790 0.042674	0.680419 0.030903	0.641661 0.033740
+++	1.141789 0.002059	1.101846 0.002742	1.231098 0.0	1.191112 0.000561	0.724910 0.036051	0.686480 0.038929	0.810661 0.029556	0.771813 0.031852
-++	1.101766 0.001528	1.061812 0.002217	1.191112 -0.000561	1.151116 0.0	0.685015 0.037190	0.646668 0.040298	0.770624 0.030248	0.731819 0.032702
+--	0.634849 -0.037562	0.594996 -0.038969	0.724910 -0.036051	0.685015 -0.037190	0.190628 0.0	0.150679 0.004330	0.280281 -0.008196	0.240179 -0.006847
---	0.596535 - 0.040951	0.556790 -0.042674	0.686480 -0.038929	0.646668 -0.040298	0.150679 -0.004330	0.110646 0.0	0.240545 -0.012253	0.200410 -0.11454
++-	0.720447 -0.030088	0.680419 -0.030903	0.810661 -0.029556	0.770624 -0.030248	0.280281 0.008196	0.240545 0.012253	0.369381 0.0	0.329409 0.001987
-+-	0.681636 -0.032717	0.641661 -0.033740	0.771813 -0.031852	0.731819 -0.032702	0.240179 0.006847	0.200410 0.011454	0.329409 -0.001987	0.289399 0.

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